PRODUCTION OF HIGH-QUALITY TEMPORARY CROWNS AND BRIDGES BY STEREOLITHOGRAPHY

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ABSTRACT

INTRODUCTION: Temporary crowns and bridges are the main elements in the treatment with fixed partial dentures. They are usually manufactured from methacrylate polymers and composites by heat-curing or CAD/CAM milling. Additive technologies (ATs) offer a number of advantages in the production of temporary dental restorations. However, there is a lack of information about the application of AT for manufacturing of provisional prostheses due to the multiple variants and complexity of their design as well as the wide variety of the 3D printing processes.

AIM: The aim of the present paper was to establish the peculiarities in the production of high-quality temporary crowns and bridges by stereolithography (SLA) with digital light projection (DLP).

MATERIALS AND METHODS: Two groups of samples – cubic (5 mm x 5 mm x 5 mm) and four-part dental bridges (1-st premolar to 2-nd molar) were printed with different layer thickness - 35 µm and 50 µm from *NextDent C+B* polymer using *RapidShape D30*.

RESULTS AND DISCUSSION: It was established that for effective production of temporary crowns and bridges with high dimensional accuracy and surface smoothness, it is necessary to take into account the peculiarities of the 3D printing process and to make corrections still at the stage of virtual model generation. Individual corrections of the dimensions along the separate axes of the virtual model have to be done with correction coefficients, depending on the construction type – crown or bridge. In order to obtain high smoothness, the construction should be positioned with the vertical axes of the teeth parallel to the printing direction (Z-axis). The number of the supports has to be increased (≥4 per tooth) for reduction of the deformations during 3D printing and final photopolymerization.

CONCLUSION: The findings in the present study could be very helpful in the development of proper construction design and technological process for improving the quality of temporary restorations.

Keywords: *temporary crowns and bridges, stereolithography, dimensional accuracy, surface roughness, production process features*

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INTRODUCTION

Temporary crowns and bridges are main elements in the treatment with fixed partial dentures (FPDs) (1-4). Their functions are related to providing pulp protection and occlusal compatibility, maintaining the position of the teeth, protection against fractures and resistance to functional loads. From aesthetic point of view, they have to posses permanent color and the necessary translucency (4,5). The provisional crowns and bridges must have satisfactory functional, very good aesthetic, prophylactic and psycho-prophylactic qualities. Furthermore, they are prototypes of the future FPDs.

At present, a variety of materials and technologies are used for manufacturing of temporary FPDs that ensure easy production, good aesthetics and relatively high hardness and strength. The materials for provisional crowns and bridges can be categorized into two main groups: 1) methacrylate polymers and 2) composites. Polymethyl methacrylate (PMMA), poly-ethyl methacrylate, polyvinyl ethyl methacrylate, bisphenol A glycidyl methacrylate, urethane dimethacrylate, etc. are mainly used (2,4,6-9). The production methods of temporary crowns and bridges include conventional technology, using heat-cured PMMA, and the relatively new CAD-CAM milling of PMMA blanks (5-7,10). Heat-cured acrylic polymers have higher strength and wear resistance than self-cured. Further, they are characterized by a stable color and easy surface treatment. Temporary constructions made from them can function successfully over a long period of time (6,7).

The application of CAD-CAM systems for milling of provisional prostheses allows the use of high-density polymers, which guarantees relatively high mechanical properties and biocompatibility. They provide short-term production of temporary restorations with high precision with respect to anatomical shape, fitting to the teeth and occlusal contacts [9,10]. These undoubted advantages of CAD-CAM systems determine their wide use in dental offices and laboratories in recent years. The implementation of 3D printing equipment in the CAM module and the partial or complete digitization of the processes from the very beginning - the initial impression, can significantly shorten the production time and provide temporary prosthetic restorations with the necessary precision and quality.

Digholkar S. et al. (5) examined the microhardness and flexural strength of materials for temporary FPDs, made conventionally from heat-cured polymer, CAD-CAM milling of PMMA and 3D printing of a microhybrid photo-cured composite. They found that the bending strength of CAD-CAM milled polymer (104.20 MPa) was the highest in comparison to the other two materials, while in terms of microhardness - the 3D printed composite was the hardest (32.77 HKN) due to the presence of filler. Tahayeri A. et al. (11) manufactured samples from the available on the market *NextDent C & B Vertex Dental* polymer, intended for temporary crowns and bridges, using a comparatively inexpensive *Form 1+ (FormLabs)* printer, running on the principle of the laser stereolithography (SLA). They found that, despite the limited accuracy of the printing system, the materials for temporary restorations, fabricated by SLA, have the necessary mechanical properties for intraoral usage. The studies of Mai HN et al. (12) have shown that crowns made with CAD-CAM systems (milling and polymer-jet 3D printing) are characterized by a higher fitting accuracy than those produced in a matrix, as the process of the polymer-jet 3D printing significantly increases accuracy of the crowns, especially in the occlusal area. According to Kim DY et al. (13) the fitting accuracy of dental crowns is influenced by the number of samples produced by microstereolithography, as the most accurate details are obtained when 3 pieces are printed on a single platform.

The literature review has shown that there is a lack of information about the application of additive technologies for manufacturing of temporary dental restorations. This is most likely due to the multiple variants of the provisional prosthesis design as well as the wide variety of the 3D printing processes. As these technologies provide accuracy and mechanical properties of the constructions higher or comparable to the conventionally manufactured, it is necessary to perform complex research which will help with their successful implementation into dental offices and dental laboratories.

AIM

The aim of the present study is to establish the peculiarities of the production of temporary crowns and bridges with high quality by stereolithography with digital light projection (DLP).

MATERIALS AND METHODS

Two groups of samples were manufactured – cubic (5 mm x 5 mm x 5 mm) and four-part dental bridges from 1st premolar to 2nd molar. They were printed using *RapidShape D30 (RapidShape)* equipment, working on the principle of DLP stereolithography. The samples were printed using *NextDent C+B* polymer, intended for temporary restorations, with two-layer thicknesses - 35 µm and the recommended by the producer 50 µm. The cubic samples were printed in two positions – parallel and inclined at 45° to the basis. The dimensional accuracy was studied by measurement of the sides and diagonals of the cubic samples and the values of the connectors between the bridge-bodies and bridge-retainers: *a1*, *a2* and *a3,* the width of the bridge bodies – *b1* and *b2* and the length of the bridges – *L*. The accuracy of the samples was evaluated by the relative difference of the dimensions (in %) with the dimensions of the virtual cube or the conventionally cast bridge being a base model. The surface roughness was studied through measurement of its average arithmetic deviation *Ra* via profile meter *Taylor Hobson Surtronik 3*. More detailed information about the specimens' fabrication and measurements can be found in the works of Dikova T. et al (14-16).

RESULTS AND DISCUSSION

The high dimensional accuracy and fitting to the prepared teeth, as well as the high smoothness of the surfaces of the temporary crowns and bridges are of particular importance for their proper functioning. On the other hand, a technological process is effective, if it ensures fast production of the details.

The temporary crowns and bridges can be fabricated by printer *RapidShape D30* using *NextDent C+B* polymer, which is designed especially for these purposes. It has been established in our previous investigations (14-16) that the samples, 3D printed with a lower layer thickness of 35 µm, are characterized by the highest dimensional accuracy and smoothness of the surfaces. The duration of the process for their production is 59 min for cubic samples and 122 min for dental bridges, which is two times longer compared to printing a 50 µm layer (recommended by the producer) – 35 min and 68 min, respectively. Moreover, the gap for the following cementation of the temporary bridges, printed with a 35 µm layer, is insufficient. Consequently, for the effective manufacturing of temporary bridges and crowns by 3D printing, it is necessary to use the recommended by the manufacturer layer thickness of 50 µm. However, in order to ensure sufficient accuracy, corrections of the objects positioning, the supports number and the details dimensions along the three axes should be done.

It has been found in our previous research (14,15) that the surfaces, parallel to the printer's basis, are characterized by the lowest roughness, followed by these, parallel to the printing direction (Z-axes). For polymeric samples of *NextDent C+B,* printed with 50 µm thickness, the *Ra* values are in the range 1.35-1.80 µm. In order to ensure low roughness within these limits, the vertical axes of the teeth of the temporary bridges and crowns must be parallel to the printing direction (Z-axes).

In this case, more supports should be added, contacting the occlusal surface, which could increase

Table 1. Relative difference (%) between the dimensions of the 3D printed cubic samples and the virtual model

Sample's Position	Horizontal		Inclined		Average Value
Position of the dimension along the axes or plane	X	Y	Y	XY	XY
Dimension type	a	b	d2	a	
Nextdent C+B, 50 µm	1.20	0.67	-2.88	0.40	0.00
Nextdent C+B, 35 µm	-0.40	0.00	-0.99	0.94	-0.11
Position of the dimension in plane	YZ	YZ	YZ	YZ	YZ
Dimension type	d1	d2	b	c	
Nextdent C+B, 50 µm	-2.40	-1.56	3.33	3.37	0.69
Nextdent C+B, 35 µm	0.56	1.00	5.34	4.66	2.89
Position of the dimension along the axes	Z		Z		Z
Dimension type	c		d1		
Nextdent C+B, 50 µm	2.00		-2.97		-0.49
Nextdent C+B, 35 µm	8.00		0.81		4.41

the resistance of the constructions to deformations both during printing and subsequent final photopolymerization. Since the production of temporary crowns and bridges with a layer thickness of 50 μm provides an uneven gap of 0.1-0.2 mm relative to the prepared tooth, for ensuring its even distribution and reduction of the deformations, it is recommended for the construction to be placed on a working gypsum pattern during the final photopolymerization.

According to our research, the 3D printing process with *RapidShape D30* equipment provides high dimensional accuracy in the X-Y plane parallel to the base (14-16). When working with a layer thickness of 50 μm, the dimensions of the objects differ from those of the virtual or real models by -0.53% to 0.85%. In crown manufacturing the actual differences could be in the range of 0.03-0.04 mm, which is negligible. However, in the production of four-part dental bridges, -0.53% represent 0.18 mm less than the actual length of 34 mm. To increase the accuracy in this case, a correction must be made on the axis with the largest dimension (X or Y), i.e. its value has to be increased by the corresponding percentage, which for *NextDent C + B* polymer is 0.44%. As for the dimensions along the direction of the Z-axis, our research shows contradictory results (Table 1). The values measured between the two walls of the cubic samples are larger by 2% to 8% as compared to the virtual model, and those measured between the two edges (the diagonals of the cube) vary between 1.93% / -2.97%. In our opinion, these discrepancies are due to the defects and the increased roughness of the walls of the cubic samples. Considering the proposed by us positions of the crowns and bridges as well as the calculated coefficients for printing with 50 μm layer thickness, in order to obtain accurate di-

Table 2. Relative difference (%) between the dimensions of the 3D printed dental bridges and the bridge-base model

Position of the Dimension along the Axes or Plane	XZ	XZ	XZ	Average Value	XZ	XZ	Average Value	Average Value in XZ	Y
Dimension	a1	a2	a3	a	b1	b2	b	(a+b)/2	L
Nextdent C+B, 50 μm	5.05	4.51	1.72	3.76	2.61	3.94	3.28	3.57	-0.44
Nextdent C+B, 35 μm	-0.44	-0.59	5.69	1.55	0.55	-2.20	-0.83	0.60	-0.59
Dimension type	Connector's width 4-6 mm				Bridge bodies' width 7-9 mm				Length 34 mm

Table 3. Algorithm for design of a virtual model and 3D printing process of temporary crowns and bridges with a RapidShape D30 printer

Technological Feature		Crown	Bridge Construction
3D printing process			
Printer		RapidShape D30	
Polymer		NextDent C+B	
Layer thickness		50 μm (recommended by the producer)	
Design of the virtual model			
Position		Vertical axes of the teeth must be parallel to the printing direction Z-axes.	
Supports number		≥4	≥4 of each tooth
Corrections of the dimensions	Along axes X or Y	0%	An increase with 0.44% on the axis with the largest size; 0% on the other axis.
	Along axes Z	Decrease with 2%	
Additional treatment			
Final photopolymerization		The construction must be placed on a working model.	

mensions along the direction of the Z-axis it is needed for their values to be reduced by 2%. Thus, the dimensions in the X-Y and Y-Z planes will be reduced by about 2.8%, which will increase the overall accuracy (Table 2).

The technological features and the algorithm for designing the virtual model and the fabricating process of temporary crowns and bridges providing high accuracy and smoothness are summarized in Table 3 and Fig. 1. For effective production of provisional crowns and bridges with high precision and smoothness using a *RapidShape D30* printer, it is necessary to take into account the peculiarities of the 3D printing process and to make corrections still at the stage of the virtual model generation. In order to ensure a relatively high surface smoothness, the construction should be positioned so that the vertical axes of the teeth are parallel to the printing direction (Z-axes). For the reduction of deformations during 3D printing and final photopolymerization, it is necessary to increase the number of supports (≥4 per tooth). Correction of the dimensions of the virtual models along the separate axes depending on the construction type - bridge or crown, will increase their accuracy.

CONCLUSION

The present study deals with the peculiarities of the production of temporary crowns and bridges with high quality by stereolithography. It is established that for effective fabrication of provisional crowns and bridges with high dimensional accu-

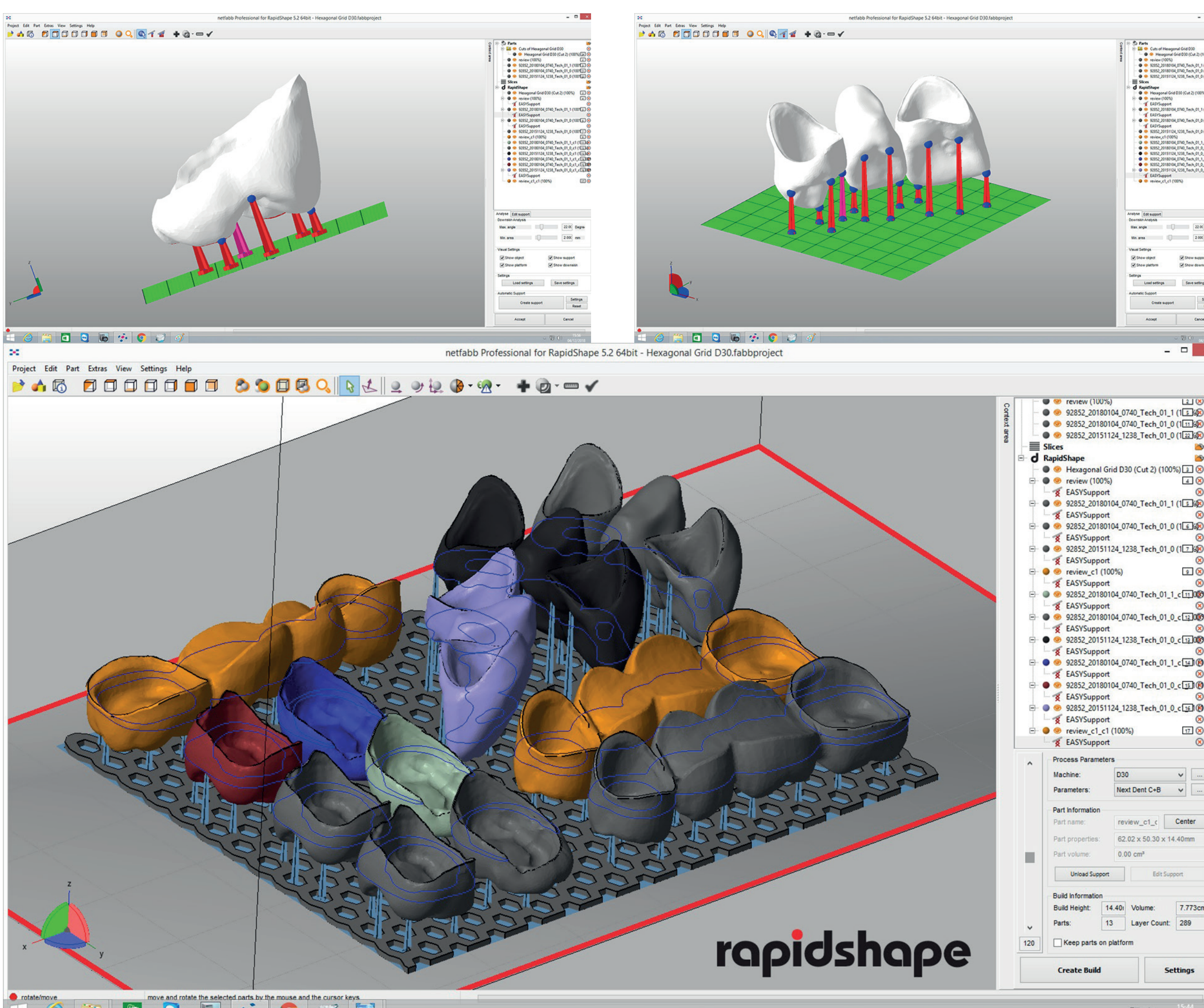

Fig. 1. Supports – a), b) and positions of the virtual models of temporary crowns and bridges – c) ready for 3D printing with RapidShape D30 (the projection of the 120 layer is marked with blue line)

racy and surface smoothness using *RapidShape D30* printer individual corrections of the dimensions along the separate axes of the virtual model have to be done. The corresponding correction coefficients, which depend on the construction type – crown or bridge, have been calculated and proposed. The construction should be positioned with the vertical axes of the teeth parallel to the printing direction (Z-axis). The number of the supports has to be increased (≥4 per tooth) for reduction of deformations during 3D printing and final photopolymerization.

The findings in the present study will be very helpful in the development of proper construction design and technological process thus improving the quality of the temporary restorations produced by DLP stereolithography.

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